VISION IN THE WATER WITHOUT A FACEMASK

by
S. M. Luria, Ph. D.
and
Jo Ann S. Kinney, Ph. D.

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NUMBER 795

Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4306.03-2050.19

Reviewed and Approved by:

Charles F. Gell

Charles F. Gell, M.D., D.Sc.(Med)
SCIENTIFIC DIRECTOR
NavSubMedRschLab

Approved and Released by:

R. L. Sphar

R. L. Sphar, CDR, MC, USN
OFFICER IN CHARGE
NavSubMedRschLab

SUMMARY PAGE

THE PROBLEM

To measure the ability of persons submerged without a facemask to estimate size and distance of objects.

FINDINGS

Although the range of visibility was markedly reduced--maximum range was only 15 feet, whereas with a mask it would have been around 200 ft--the divers were able to estimate the distance of visible objects quite accurately. There was little difference between the distance-estimates of visible objects at a given distance with and without the facemask. Similarly, errors in size-estimates were no greater without the mask, although they were in the opposite direction: size was underestimated rather than overestimated. Finally, stereoacuity was very much reduced without the facemask, similar to the reduction in resolution acuity found before. There was a moderate correlation between stereoacuity in air and in the water.

APPLICATION

Divers without a facemask are able to estimate the size and distance of visible objects as accurately as with a mask. Individuals with refractive errors do as well as those whose vision is normal.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit M4306.03-2050. The present report is Number 19 on this work unit. It was submitted for review on 23 October 74, approved for publication on 4 November 74, and designated as NavSubMedRschLab Report No. 795.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

In a study to determine the visual acuity of divers in the water without a facemask, three basic visual functions were examined.

Distance- and size-estimates and stereoacuity judgments were made in the water by divers both with and without a facemask. Without the mask, only stereoacuity was markedly degraded. Distance-estimates were slightly more accurate, despite a great decrease in the range of visibility. Size-estimates were slightly too small. Divers with refractive errors did not appear to be more handicapped than those with normal visision.

Clip and Mail Form for Change of Address:

\- -

TO: Officer in Charge, Naval Submarine Medical Research Laboratory, Attn: Code 4B23

SUBJ: Change of Address

1. I/We wish to continue to receive NavSubMedRschLab Reports, however, the following change of address should be noted:

New Address: ______________________________

____

____

Old Address: ______________________________

____

____

VISION IN THE WATER WITHOUT A FACEMASK

INTRODUCTION

Almost no attention has been paid to the measurement of the various visual processes of divers in the water without a facemask. Yet there may be occasions when an individual, such as an escaping submariner or a downed pilot, may find himself in the water without a mask, and it would be of interest to know how his basic visual functions would be affected.

It is well known that the lens of the eye accounts for only a small fraction of the refractive power of the eye; at least two-thirds of the refraction of light rays is accomplished at the corneal-air interface. When the eye is immersed in water, this interface is lost, and with it most of the refractive power of the eye.

The limits of visual acuity were studied under such conditions some years ago; Luria and Kinney[1] found that even under the best conditions, visual acuity was reduced to about .1 compared to better than 1.0 in air. In the present study, we have examined three other basic visual functions, stereoacuity, size-estimation and distance-estimation. Taken together, the four sets of results should give a good indication of what can be seen.

METHOD

Apparatus and Procedure:

The experiment was carried out in the well-lighted, clear water of a 10 x 25 m swimming pool. The general procedure was to test half of the subjects first with a facemask and half without a mask on each test.

1. Distance estimates - The subject, positioned by a chin-rest, estimated the distance in feet of a fluorescent orange cylinder (12 cm high and 7 cm diameter) suspended at eye-level at three distances, randomly chosen from 1 to 6 m. The view of the target was blocked between judgments.

2. Size estimates were obtained for targets positioned 60 cm from the subject. The subject's task was to choose from a series of 19 black disks (whose diameter varied from 3.2 to 10.16 cm) those disks which appeared to have the same diameter as a golf ball and a baseball. The disks were suspended in a haphazard arrangement on a white vertical background. The subjects reported their choices without touching the disks.

3. Stereoacuity was measured in two ways. Equidistant localization thresholds were obtained in the water using three pairs of targets. All targets were flat plates 60 cm long and painted fluorescent orange. The widths of the three pairs were 2.5, 10, and 30 cm. The left target was suspended in the water at a fixed position; the right target was lowered into the water at a lateral separation of about 10 cm from the fixed target but at a different distance. The subject signalled the experimenter how to set the right target so that both appeared to be

equidistant. There were three trials with each pair.

At the mean viewing distances chosen by the subjects, 1.5, 2.6 and 3.0 m, the plates subtended 0.95, 2.2 and 5.7°, respectively.

For the perception of size and distance, a comparison was made between vision in the water with and without a facemask. For stereoacuity, however, preliminary data showed it to be so poor that such a comparison was unnecessary, and the thresholds were obtained only without a mask.

However, in order to relate acuity to the subject's refractive errors, thresholds were subsequently measured in air using the much more sensitive method of constant stimuli and the variability of the equidistant settings was used for analysis. The subjects wore -40 diopter prisms (but not their spectacle corrections) which reduced their refractive power by roughly the same amount as the eye-water interface. Additional subjects were recruited and a total of 11 were tested, as indicated in Table I. Stereoacuity was measured with a three-rod Howard-Dolman apparatus. The vertical, black rods stood in a box with a gray front 46 cm wide and 36 cm high. The rods were 1.57 cm thick, 7.6 cm apart, and were seen against a white background.

Viewing distance again varied somewhat for each subject, but at a typical distance of 40 cm, the rods subtended 2.25° at a separation of 10.75°.

Table I. Refractive corrections of the subjects (prism diopters)

Subjects		Left eye		Right eye	
Emmetropes:	EH	0.00		0.00	
	TP	0.00		0.00	
	CM	0.00		0.00	
	SL	-0.50*		-0.50	
Myopes:	DW	-6.00	-1.50 x 180	-5.25	-1.25 x 180
	BC	-1.25		-1.00	-0.75 x 180
	MS	-3.50	-0.25 x 045	-2.50	-0.25 x 045
	LG	-2.50	-0.50 x 090	-2.00	-0.50 x 110
Hyperopes:	JK	+4.75	-0.50 x 090	+4.50	-0.50 x 090
	LR	+2.00		+2.00	
	DK	+0.75	-0.50 x 095	+0.75	-0.25 x 115

*The first author has invoked executive privilege and declared himself still an emmetrope.

Subjects:

Six members of the laboratory staff served as subjects in the water. They were two emmetropes (SL, EH), two hyperopes (JK, LR), and two myopes (DW, BC). The two emmetropes and one of the hyperopes (JK) were experienced in underwater experiments. Five additional subjects, also laboratory members, participated in the stereoacuity test in air. The refractive corrections of the subjects are given in Table I.

RESULTS

Distance estimates:

Table II shows the mean ratios of the estimated distance of the target to its actual distance for the three pairs of subjects with and without a mask. The mean ratio with the mask was .74, about what would be expected from optical considerations. This ratio indicates that the target appeared to be about three-quarters its actual distance. Without the mask, the mean ratio increased to .88. The sets of estimates with and without a mask are reliably different (paired $t = 2.38$, $df = 5$, $p > .05$). It is clear that the lack of a facemask does not increase the errors of divers' distance-estimates. Indeed, they are slightly more accurate without the mask than with it. Differences among individuals were much larger than any attributable to type of refractive error.

Figure 1 shows the two sets of estimates. The lines are least squares regression lines. An analysis of variance indicates that their slopes are not reliably different. That is, there is no indication that the distance estimates made without the mask are changing relative to those made with the mask as the target-distance increases.

Size estimates:

Table III gives the ratios of the diameters of the disks which appeared

Table II. Mean ratio of estimated distances to actual distances

Subjects		Mask	No Mask
Emmetropes:	SL	.92	1.02
	EH	.36	.58
Myopes:	DW	.81	.80
	BC	.72	.79
Hyperopes:	JK	.84	.97
	LR	.78	1.11
Mean		.74	.88

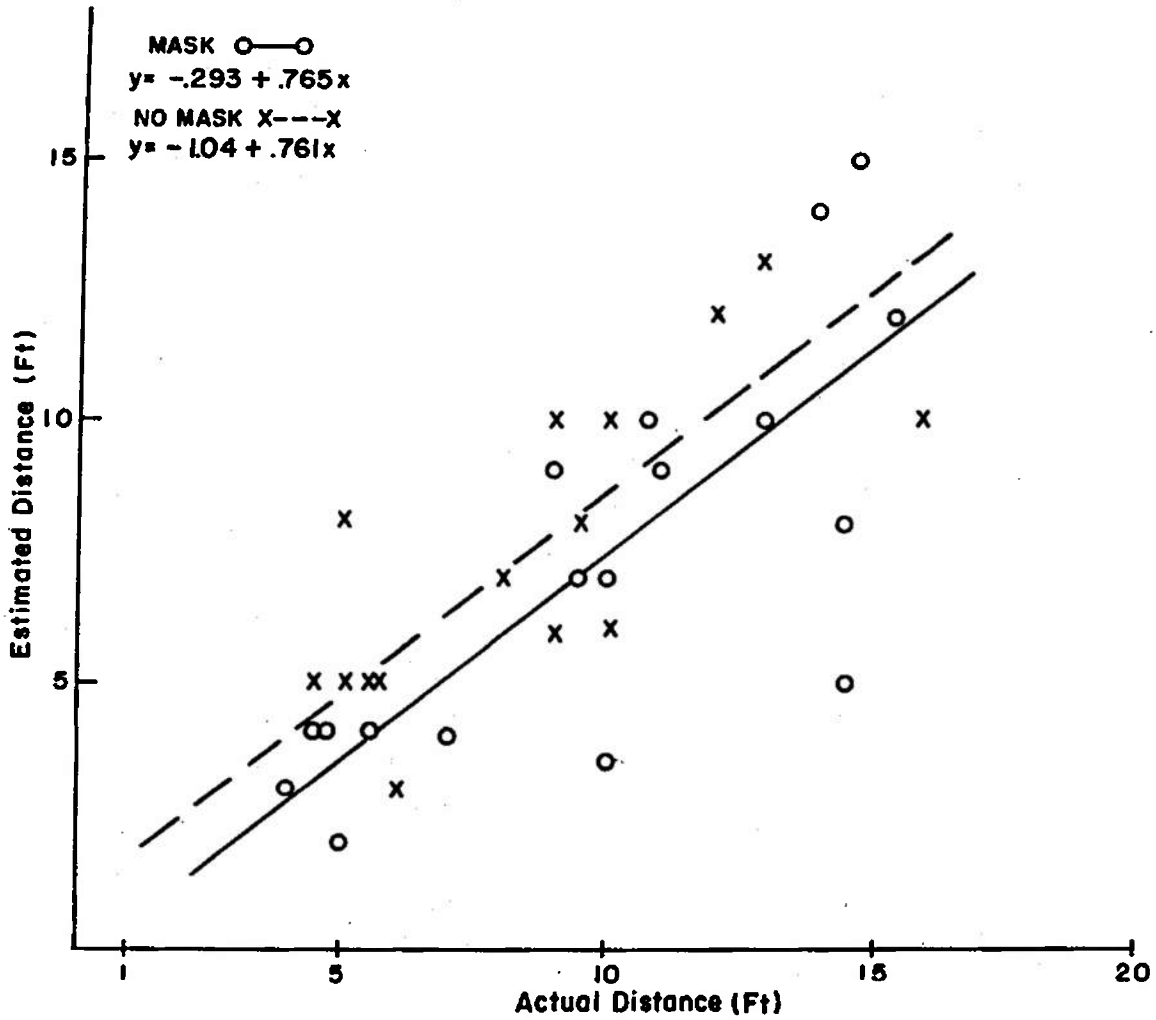

Fig. 1. Distance estimates of targets at various physical distances made both with (o) and without (x) a facemask

to be the same diameter as a golf ball and a baseball to the actual diameters of the balls. With the mask, the mean ratios were .93 and .87 for the golf ball and baseball. As expected, because of the magnification of the retinal image as a result of the refraction of the light-rays, the subjects tended to choose disks whose diameters were smaller than the actual diameters of the balls.

When no mask was worn, every disk chosen except two was too large (paired $t = 2.77$, $df = 5$, $< .05$), whereas wearing the standard mask results in the divers choosing disks that are too small. The magnitude of the error in both cases is approximately the same.

Stereoacuity:

The mean equidistance localization errors for the three sets of targets are given in Table IV for the entire group. Errors were appreciably larger with the smallest pair of targets, and the subjects had to come progressively closer

Table III. Mean ratios of diameters of disks chosen to actual diameters of golf ball and baseball

Subjects	Mask		No Mask	
	Golf	Baseball	Golf	Baseball
Emmetropes				
SL	0.75	0.70	1.19	1.22
EH	0.75	1.05	1.19	1.26
Myopes				
DW	0.75	0.86	0.95	1.05
BC	1.27	1.00	1.05	1.05
Hyperopes				
JK	0.77	0.62	0.83	1.10
LR	1.27	1.00	1.27	1.10
Mean	0.93	0.87	1.08	1.13

Table IV. Mean stereoacuity thresholds (η_σ in sec arc), mean localization error (cm) and mean viewing distance (m) for targets of different size

	Small	Medium	Large
Stereoacuity	420	128	175
Localization error	7.1	7.0	12.5
Viewing distance	1.5	2.6	3.0

in order to make a judgment as target-size decreased. The mean viewing distance for the smallest targets was 1.5 m, whereas all the subjects were able to judge the largest targets at a distance of 3 m. The best mean value however was over 100 seconds of arc, far worse than the mean of around 10 seconds of arc expected with a face-mask.[2,3]

The precision of the equidistance judgments obtained in air for the 11 subjects wearing their corrections is plotted against their spherical refractive error in Figure 2A. There is no marked relation between the two measures.

The stereoacuity of the subjects obtained in air while wearing -40 ▲ prisms (but not their spectacle corrections) is shown in Fig. 2B. The best performance was again only around 200 sec arc, achieved by the emmetropes. With increasing refractive error in either direction, performance declined. The

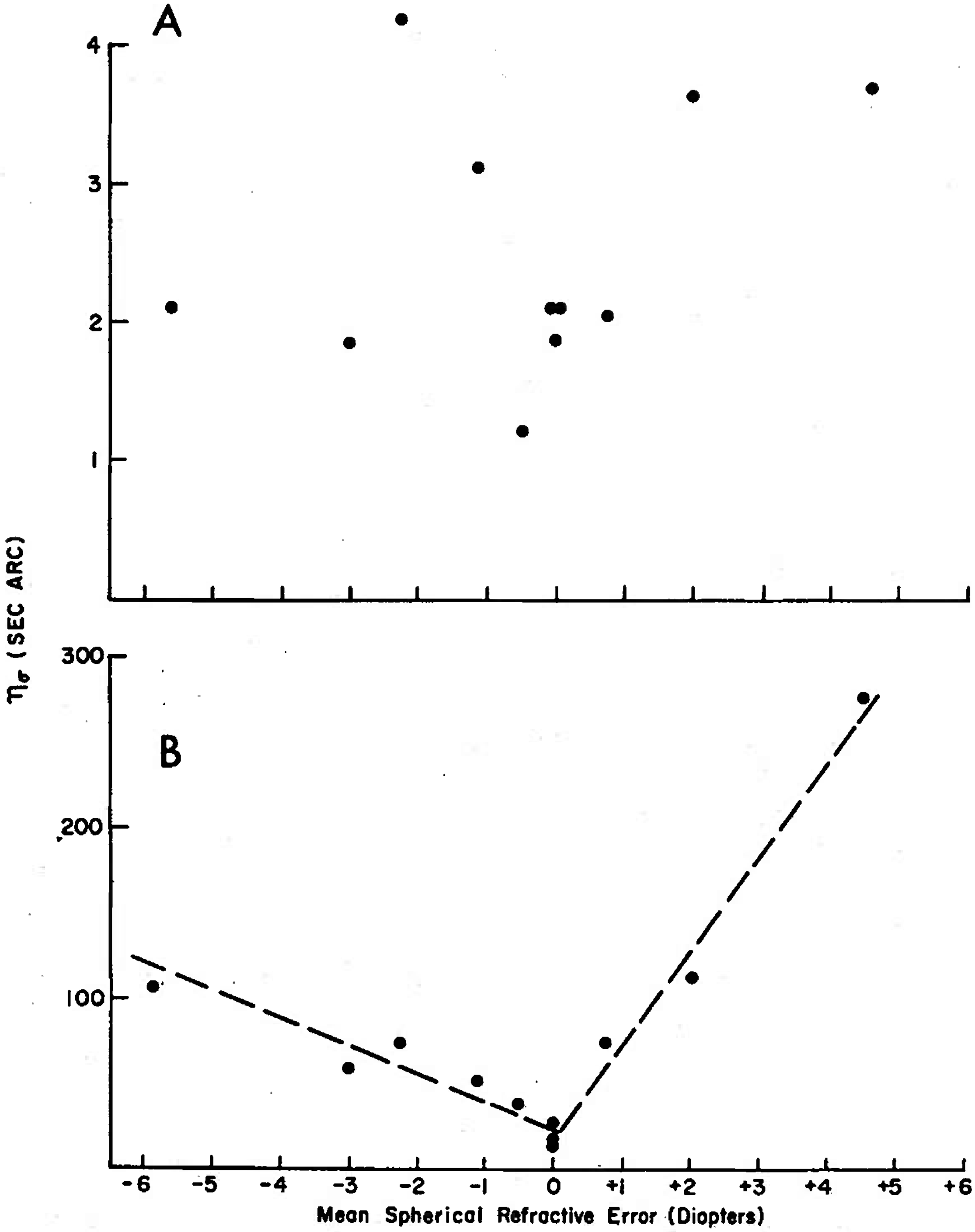

Fig. 2. Variability of equidistant localization settings (η_σ in seconds of arc) as a function of the observer's mean spherical refractive error (A) in air, and (B) in the water without a facemask. Note the different ordinates in each graph.

The slope of the function for the hyperopes is steeper than that for the myopes; that is, for a given magnitude of refractive error, the hyperopes had poorer stereoacuity than the myopes.

There is a moderately high relationship between the two sets of acuities ($r = .54$, $p < .10$), but a comparison of the two graphs suggests that the water may be having some effect; the myopes with refractive errors between 1 and 2.5 D. had very poor stereoacuity in air, but relatively good acuity in the water.

DISCUSSION

These results show, surprisingly, that not all visual processes are greatly degraded in the water without a facemask. Distance estimates were more accurate without the mask. It must be noted that the subjects produced the same regression lines with and without a mask, although the range of visibility without the mask was greatly reduced. With the mask, the divers had no trouble seeing the full length of the 25 m pool. Without the mask, they could see no farther than around 4 or 5 m, but they had no way of knowing, of course, exactly what their range of visibility was. Despite the fact that the divers could not know at what distance the target would fade out, their distance estimates were reasonably accurate as long as the target was visible.

Since the target was extremely blurred except when very close - indeed, usually it was nothing more than a luminous orange blur - the question arises as to what cues the subjects were using to make their estimates. The kinesthetic sensations arising from accommodation and convergence are sometimes suggested. Zajac[4] and Davson[5] believe that they do not contribute much to the ability to assess distance. Leibowitz and Moore[6] found that such cues affect the perception of size only for targets within .5 m. But it is possible that the disagreements arise from the existence of individual differences: Richards and Miller[7] reported that some subjects can use convergence as a cue to depth and others cannot. However, their experiment involved targets up to a distance of only 2 m. Similarly, Oyama[8] has concluded that both perceived size and perceived distance can be determined by visual angle and convergence, but his study was also carried out with a viewing alley only slightly longer than 2 m.

Size-estimates were also not degraded without the mask. With the mask, the subjects underestimated the size of the target-disks by about 10%; without the mask, they overestimated its size by about 10%. We are not certain if one error would be considered more serious than the other.

The overestimation of size would, in general, be expected, since an unfocused retinal image is larger than a focused one. One might expect that myopes would experience less defocusing of the retinal image in the water than either emmetropes or hyperopes and would therefore pick smaller disks. Their mean values, were, in fact, smaller, but the data are too variable for any definitive statements.

In this study, only stereoacuity was markedly impaired by the lack of a facemask. Much of the reason for the very poor stereoacuity thresholds in the water is (probably) simply a failure of resolution acuity. Note that in the previous study, visual acuity was degraded by about a factor of at least 10, and that in the study stereoacuity was also degraded by somewhat more than a factor of 10.

The question immediately arises, however, as to why the ability to perceive the relative distance between two targets should be lost when the ability to localize one target is apparently largely unimpaired? Table IV appears to answer this question quite clearly. Note that the mean localization error was always less than 12.5 cm. This is extremely poor compared to the errors of less than 2 cm that are commonplace in air. But as distance-estimates, such errors would be quite acceptable under any conditions. In other words, stereoacuity in the water is considered to be extremely poor because it is being compared to a very accurate baseline, whereas distance-estimates are considered to be good because they are compared to a rather poor baseline. It is clear that although a great deal of sensitivity is lost without the facemask, most divers retain a reasonably good idea of where visible objects are localized.

In summary, divers without a facemask lose most of their resolution and stereoacuity, but neither the ability to localize the distance of visible objects nor the ability to estimate their size is impaired.

Of most practical importance is the indication that, for the most part, individuals with refractive errors are not disproportionately handicapped in any of the tasks, when compared to people with normal vision. The present results reinforce our previous conclusions that refractive errors do not handicap a SCUBA diver. Men with poor vision can serve as divers, since corrective spectacles can easily be built into their facemasks. In the event that the mask is lost in the water, they are no worse off than would be divers with normal vision without their masks.

REFERENCES

1. Luria, S. M. and J. A. S. Kinney. Visual acuity under water without a face mask. NavSubMedRschLab Rep. No. 581, May 1969; Acuity-luminance function for extreme refractive error. Am J Optom 47, 205-211, 1970.

2. Luria, S. M. and J. A. S. Kinney. Stereoscopic acuity underwater. Am J Psychol 81, 359-366, 1968.

3. Luria, S. M., S. H. Ferris, C. L. McKay, J. A. S. Kinney, and H. M. Paulson. Vision through various SCUBA facemasks. NavSubMedRsch Lab Rep. No. 734, Dec 1972. (Also "A comparison of scuba facemasks" in Science Diving Intl: Proceedings of 3rd Scientific Symp. of CMAS, N. C. Flemming, ed. 1973).

4. Zajac, J. L. Convergence, accommodation, and visual angle as factors in perception of size and distance. Am J Psychol 73, 142-146, 1960.

5. Davson, H. The physiology of the eye, Academic Press, N.Y. 1972.

6. Leibowitz, H. and D. Moore. Role of changes in accommodation and convergence in the perception of size. J Opt Soc Am 56, 1120-1123, 1966.

7. Richards, W. and J. F. Miller. Convergence as a cue to depth. Percept & Psychophys 5, 317-320, 1969.

8. Oyama, T. Perceived size and perceived distance in stereoscopic vision and an analysis of their casual relations. Percept & Psychophys 16, 175-181, 1974.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

VISION IN THE WATER WITHOUT A FACEMASK

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Interim report

5. AUTHOR(S) *(First name, middle initial, last name)*

S. M. Luria and Jo Ann S. Kinney

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
4 November 1974	9	8

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. M4306.03-2050.19	NavSubMedRschLab Report No. 795
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Research Lab. Box 900, Naval Submarine Base Groton, Connecticut 06340

13. ABSTRACT

Distance- and size-estimates and stereoacuity judgments were made in the water by divers both with and without a facemask. Without the mask, only stereoacuity was markedly degraded. Distance-estimates were slightly more accurate, despite a great decrease in the range of visibility. Size-estimates were slightly too small. Divers with refractive errors did not appear to be more handicapped than those with normal vision.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater vision						
diving accidents						
vision without a face mask						